VIBRATION ANALYSIS OF A BEAM STRUCTURE ATTACHED WITH TWO DYNAMIC VIBRATION ABSORBERS

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Dedicated specially to my parents
Jaini Bin Mahli & Zainab Balitang,
My beloved husband and family
All those who have been a great help in the completion of this thesis
My love to all of you will remain forever…

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بسم الله الرحمن الرحيم

In the name of Allah, the Most Gracious, the Most Merciful

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ABSTRACT

A fixed end beam is a structural element supported at both sides which carries load primarily in flexure that may experience vibration as it does carry vertical loads and gravitational forces. Its exposure to vibration can lead to excessive deflections and failure of to the structure. The aim of this research is to develop the application of dynamic vibration absorber on a fixed end beam structure. A classical mathematical model based on dynamic vibration absorber theory is improved by an analytical derivation until two degree of freedoms. The theoretical model is verified by experimental works. In experimental, two vibration absorbers was fabricated to be installed to the beam in four different conditions; and subjected to a force vibration frequency loading using an exciter. The resonance frequencies of interest were 11.23Hz and 35.45Hz. The vibration level that occurred on the beam is measured by comparing the effect of absorber presence to see the reduction in its amplitudes. Based on the experimental and theoretical analysis, both shows reduction in the beam amplitudes. From those results can be concluded that the dynamic vibration absorber has an ability to reduce and suppresses the beam vibration whereas the third condition has been chosen as the best arrangement where the persistent reduction results recorded 95 and 99 percents reduction of first and second DVA respectively. The knowledge gained from this research can be used to minimize the vibration amplitude of a structures and machines, increasing their life-span simultaneously. The other benefit comes from this research in specific or potential application aspect is it could control vibration in building or bridge structure and airplane wing flutter control.

ABSTRAK

Rasuk tetap merupakan satu struktur yang disokong pada kedua-dua hujung yang mungkin menanggung beban lenturan akibat getaran yang berpunca daripada beban menegak dan daya graviti. Pendedahan rasuk ini kepada getaran dalam satu jangka masa yang lama akan menyebabkan berlakunya lenturan yang berlebihan yang boleh mengakibatkan kegagalan pada strukturnya. Tujuan utama kajian ini dijalankan adalah untuk membangunkan aplikasi penyerap getaran dinamik pada struktur rasuk tetap. Model matematik klasik berdasarkan teori penyerap getaran dinamik ditambahbaik dengan satu terbitan analisis sehingga dua darjah kebebasan. Model teori ditentusahkan melalui ujikaji eksperimen. Untuk eksperimen, dua penyerap getaran telah difabrikasi untuk dipasang kepada rasuk dalam empat keadaan yang berbeza dan dikenakan beban getaran yang berlainan frekuensi dengan menggunakan penggetar. Frekuensi resonan yang menjadi tumpuan kajian adalah pada 11.23Hz dan 35.45Hz. Tahap getaran yang terhasil pada rasuk tetap diukur dengan membandingkan kesan kehadiran penyerap getaran untuk melihat pengurangan dalam amplitudnya. Data yang diperolehi menunjukkan terdapat pengurangan pada nilai amplitud rasuk bagi kedua-dua kaedah. Hasil daripada keputusan itu dapat disimpulkan bahawa penyerap getaran dinamik mempunyai keupayaan untuk mengurangkan dan menyekat getaran di mana penyerap getaran yang diletakkan dalam keadaan ketiga dipilih sebagai yang terbaik antara semua keadaan di mana pengurangan amplitud sebanyak 95 dan 99 peratus dicatat oleh penyerap getaran pada mod pertama dan kedua. Pengetahuan yang diperolehi daripada kajian ini boleh digunakan untuk meminimumkan amplitud getaran pada struktur dan mesin, sekaligus memanjangkan jangka hayatnya. Kelebihan lain daripada kajian ini secara spesifik atau dalam aspek potensi aplikasi adalah ia boleh diguna untuk mengawal getaran pada bangunan atau struktur jambatan dan juga sayap kapal terbang.

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LIST OF SYMBOLS AND ABBREVIATONS

D,d	-	Diameter
l	-	length
m	-	mass
r	-	radius
b	-	width
t	-	thickness
k	-	linear spring stiffness
f	-	frequency (Hz)
F, f	-	force
g	-	acceleration constant
ω	-	undamped circular frequency (rad/s)
t	-	time
X, *x*	-	amplitude
		displacement
cm	-	centimeter
m	-	meter
∞	-	infinity
Ω	-	natural circular frequency (rad/s)
DVA	-	dynamic vibration absorber
UTHM		- *Universiti Tun Hussein Onn Malaysia*

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CHAPTER 1

INTRODUCTION

Until early this century, machines and structures usually had very high mass and damping, because heavy beams, timbers, castings and stonework were used in their construction. Since the vibration excitation sources were often small in magnitude, the dynamic response of these highly damped machines was low. However, with the development of strong lightweight materials, increased knowledge of material properties and structural loading, and improved analysis and design techniques, the mass of machines and structures built to fulfil a particular function has decreased. Furthermore, the efficiency and speed of machinery have increased so that the sources which can create intense vibration problems. The demands made on machinery, structures and dynamic systems are also increasing, therefore the dynamic performance requirements are always rising. There have been very many cases of systems failing or not meeting performance targets because of resonance, fatigue and excessive vibration of one component. Because of the very serious effects which unwanted vibrations can have on dynamic systems, it is essential that vibration analysis be carried out as an inherent part of their design, when necessary modifications can most easily be made to eliminate vibration, or at least it as much as possible. To summarize, present-day machine and structures often contain high-energy sources which create intense vibration excitation problems, and modern construction methods resulted in systems with low mass and low inherent damping. Therefore careful design and analysis is necessary to avoid resonance or undesirable dynamic performance (Beards, 1995).

1.1 Research background

Vibration is mechanical oscillations, produced by regular or irregular period movements of a member or body from its rest position. Vibration can be a source of problem at an engineering level because resulting in damage and loss of control of equipment, and thus reducing the efficiency of operation in machines. Vibration can also cause a discomfort at a low level and at a high level it can risk the person safety (Inman, 2008).

Each vibrating structure has tendency to oscillate with larger amplitude at certain frequencies. These frequencies are known as resonance frequencies or natural frequencies of the structure. At these resonance frequencies, even a small periodic driving force can result in large amplitude vibration. When resonance occurs, the structure will start to vibrate excessively.

The primary method of eliminating vibration is at a source by designing the equipment and ensuring control over the manufacturing tolerances. Others method that can reduce the vibrations that generated by machinery is by modifying the system so that the natural frequencies are not close to the operating speed, to prevent large responses by including damping, install vibration isolating devices between adjacent sub-systems and the other way is include auxiliary mass into the equipment to reduce the response and absorb vibration (Ramamurti, 2008).

In this research, a new control strategy has been tested in order to absorb vibration. This vibration absorbing devices demonstrated as a good vibration absorber when applied on fixed-fixed end beam. In designing a good vibration absorber, the vibrations characteristic need to be studied completely.

Theoretically, every vibration system can be modelled by an equivalent mass-spring vibration system. The excessive vibration can be reduced by mean of a Dynamic Vibration Absorber (DVA). DVA is a device consisting of an auxiliary mass–spring system which tends to ‘absorb’ the vibration of a system to which it is attached (Rao, 2005; Inman, 2008). A classical DVA consists only a single pair of an auxiliary mass-spring system. This classical DVA only useful for a single degree of freedom system (Bonsel *et al.*, 2004; Wong *et al.*, 2007; Khazanov, 2007), hence limiting its application prospects. Figure 1.1 illustrates the result using dynamic vibration absorber.

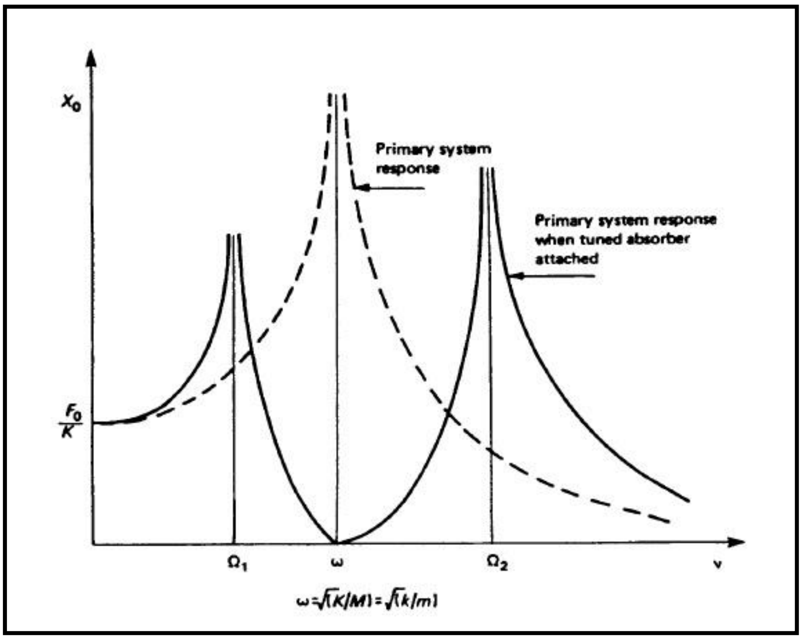

Figure 1.1 : Amplitude- frequency response for system with and without tuned absorber (Beards, 1995)

Figure 1.1 shows the response of a system with and without the use of an absorber. In general, without absorber the primary system has a high peak at certain frequency which indicates the mode of the system. It can be seen from the figure that the absorber, while eliminating vibration at the known impressed frequency of the primary structure, introduces two resonant frequencies Ω_1 and Ω_2. In practice, the operating frequency must therefore be kept away from the frequencies $\Omega 1$ and $\Omega 2$. In addition, the argument states that the two invariant points in the frequency response curve of the primary system, its response amplitude is independent of the damping of the absorber system. The stiffness value that results in equal amplitudes at the invariant points is taken to be optimal.

The problem of vibration of a beam is of intrinsic interest because the beam represents the simplest of all engineering structural. The subject of vibrations is of fundamental importance in engineering and technology. In this research project, an analysis of a DVA for a multi degree of freedom system i.e. beams structures is going to be investigated. This special DVA can be used to control the vibration level of a building built in earthquake prone area, to control the vibration level of a bridge exposed to high speed or turbulence wind and to control airplanes wing flutter.

1.2 Problem statement

Excessive vibration in engineering systems are generally undesirable and therefore avoided for the sake of safety and comfort. Vibration has been known as the factor of disturbance, discomfort, damage and destruction. It could also lead to excessive deflections and failure on the machines and structures. Exposure to vibration for a long period also can be harmful where it causes disease and muscular-skeletal pain. Thus, vibration needs to be eliminated with the effective ways to prevent all the bad effects. It is possible to reduce untoward amplitudes by attaching to the main vibrating system an auxiliary oscillating system. Therefore, this study was undertaken to reduce the risk stated by producing a new design of dynamic vibration absorber (DVA) attached to a structure called fixed-fixed end beam.

Most of researches focus on the applications of absorbers in the system under harmonic excitations with a single frequency. However, many systems in real applications are excited more than two frequencies. In addition, only few research done in study the characteristics of DVA involving two DVAs in a system. Due to these circumstances, a research theoretically and experimentally using DVA which tuned up to second mode need to be conducted.

1.3 Research aim

This research aims to study on absorber system and its tuning for a fixed-fixed end beam.

1.4 Objective (s) of the research

The main objective of this research is to study the vibration characteristics of a new designed dynamic vibration absorber attached on fixed-fixed beam subjected to force vibration frequency loading.

Based on the research gaps identified in literature survey, this study embarks on the following objectives;

i) To develop a theoretical mathematical model for the development of DVA for two degree of freedom system based on classical vibration absorber equation.

ii) To verify the theoretical model of the DVA by experimental works.

iii) To determine the vibration characteristics of a vibration system attached with the developed DVA analytically and experimentally.

1.5 Scopes

The research is focused on fixed-fixed end beam subjected to two frequency loading. This research is limited according to the scopes below:

(a) Theoretical analysis to tune the DVA to the beam.
- The analytical derivation only presented for the first two degree of freedoms.

(b) Calculation to determine the beam dimension so its do not exceed the frequencies produced by exciter motor.
- The speed control of the motor is up to 3000 rev/min.

(c) Design and fabrication the beam holder
- The beam rig designing process are restrained to the experimental lab equipment at UTHM vibration laboratory.
- Fabricated in 2 pieces so that the beam attachment could be fixed at both sides.

(d) Determine the vibration levels of the beam by running a force vibration test so that a comparison before and after using DVA could be obtained.
- This initial test run conduct until reach the motor‘s maximum speed.

(e) Calculation work to determine the appropriate design of DVA to get the optimum tuned mass absorber for the beam.
- The optimum parameters such as stiffness, mass and natural frequency.
- Calculate the *l*, length for the both sides absorber flyers.

(f) DVAs fabrication
- Most of the absorber parts are made of aluminium material.

(g) Experimental work to measure the beam amplitude after mounting DVA.
- Two DVAs attached to the structure and vibrated using shaker.
- Conducted at vibration laboratory, UTHM.
- Check the optimum tuned mass absorber for fixed-fixed beam.

1.6 Expected outcomes

The results from this research is expected that the proposed dynamic vibration absorber will absorb the structure vibration levels at constant frequency range. Subsequently, it will achieve the objective where the vibration characteristic of a dynamic vibration absorber attached on a fixed-fixed beam is studied. Figure 1.2 describes the expected amplitude-frequency response obtained before and after using two DVAs. Refer to the graph, the important thing is that after using the absorbers the structure primary amplitudes expected to be lowered at certain frequency.

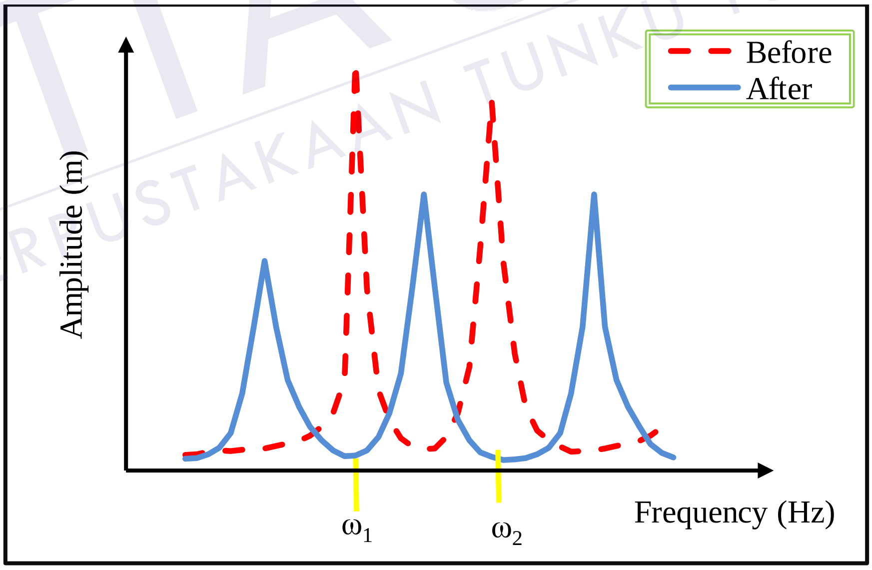

Figure 1.2 : Expected amplitude-frequency response using DVA

1.7 Significant of research

In engineering history, excessive vibration has been a common problem in causing the fatigue life of structures shorter and the performance of machines reduces. The intensity of vibration sources around us is increasing and tolerances on allowable vibration levels are becoming more and more stringent. From this phenomena, we know that vibration affects the machines and structures life span. Due to this, it is necessary to come out for a solution by solving from its root.

Vibration also can be harmful and therefore should be avoided. The most effective way to reduce unwanted vibration is to suppress the source of vibration. Above this condition, this research was carried out to understand the vibration characteristic in order to design a dynamic vibration absorber due to the needs of vibration protection itself. As a result, it gave an idea on how to produce an effective absorber. The knowledge gained from this research can be used to minimize the vibration amplitude of a structures and machines, increasing their life-span simultaneously. A complete understanding of vibration is needed involves in the analysis and design of a vibration absorber devices so this are the importance why this study should be conducted.

This research also has its own novelty in theories and knowledge whereas the finding of this research is instrumental in terms of identifying key of theoretical and mathematical model in development of DVA for multi degree of freedom systems. The other benefit comes from this research in specific or potential application aspect is it could control vibration in building or bridge structure and airplane wing flutter control.

CHAPTER 2

LITERATURE STUDY

This chapter gives insight into vibration theory, vibration control, beam, dynamic vibration absorber (DVA) and previous research done on dynamic vibration absorber.

2.1 Concept of vibration

Variations in physical phenomena that take place more or less regularly and repeated themselves in respect to time are described as oscillations. In other words, any motion that repeats itself after an interval of time is called vibration or oscillation. The theory of vibration deals with the study of oscillatory motion of bodies and the associated forces. The oscillatory motion shown in Figure 2.1 below is called harmonic motion and is denoted as

$$x\,(t) = X\,cos\omega t \tag{2.1}$$

The theory of vibration deals with the study of oscillatory motions of bodies and the forces associated with them (Rao, 2005). Vibration also is the study of the repetitive motion of objects relative to a stationary frame of reference or nominal position (usually equilibrium).

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